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Systems Engineering Applied Leading Indicators—Enabling Assessment of Acquisition Technical Performance

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Abstract

This paper discusses research in developing DoD acquisition metrics associated with Systems Engineering activities that may provide greater insight into the technical performance of development programs. These metrics are called Systems Engineering Applied Leading Indicators (ALI). We examine current development of single and multi-factor ALIs that have been developed during the past year at the Naval Air Systems Command (NAVAIR) in Patuxent River, MD. The development methods, early examination of ALI utility, and user acceptance are discussed. The authors have been embedded with the NAVAIR Systems Engineering Development and Implementation Center (SEDIC) (the center of this work for NAVAIR) as part of this ALI exploration.

Acknowledgments

The authors have been working in close collaboration with the members of the NAVAIR SEDIC team at NAS, Patuxent River, MD, in the conduct of the subject research. Much of the foundational work referred to in this paper is a result of their efforts. The team includes Juan Ortiz, Paul Hood, and Javier Sierra of NAVAIR, and Gregory Hein, Johnathan Gilliard, and Tina Denq from Booz Allen Hamilton.

Introduction and Problem Definition

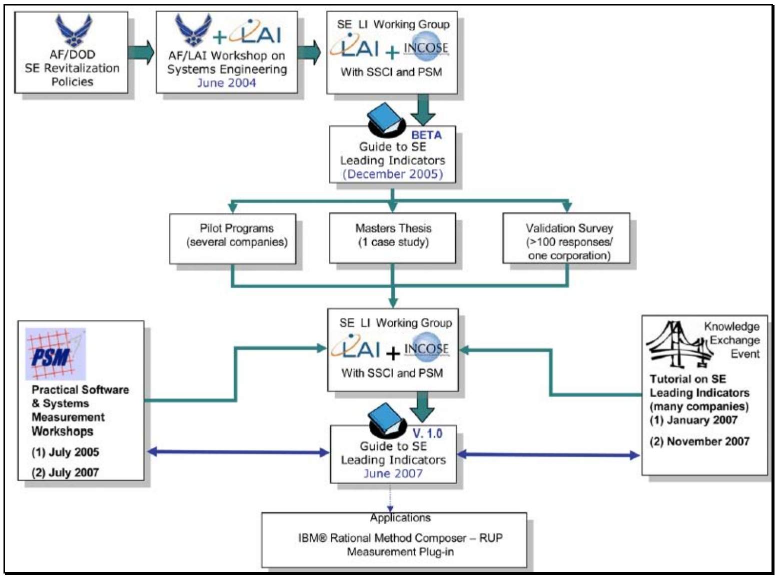
Background

What is the role of systems engineering (SE) in the acquisition and development of systems? The professional society for SE (INCOSE) defines SE as follows:

> *Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal**. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.*** (INCOSE, 2010)

The principles, practices, and methods of SE are well defined and long practiced by Government and industry (INCOSE, 2010; NASA, 2007; NAVY, 2004). The value added by disciplining the development of a system is well appreciated. In the mid 1990s, SE practices were augmented with the concepts of SE metrics (INCOSE, 1995; 1998; Roedler, 2005). Early implementation of these metrics has been directed at the measurement of the performance of the SE process itself.

In the bolded part of the definition above, SE continues to expand its benefits to include not only the development team but also all customers and stakeholders who are maximally interested in a project/program that is delivered satisfying cost, schedule, as well as technical goals. There is now interest in the SE community on how to expand, define, and derive metrics and methods that would provide predictive or prognostic indicators of the success of a development effort as a whole (see **Error! Reference source not found.**) (Rhodes, Valerdi & Roedler, 2009). While the existing SE metrics and methods have typically produced lagging and inferred indicators of the health and status of a development effort, current efforts and research are now underway to examine how to provide direct *leading indicators*, derived from SE and *applied* to understanding and predicting the technical trajectory of the aggregate development effort. Because we are *applying* and focusing the concepts of SE leading indicators (Roedler & Rhodes, 2007), we will refer to this concept as SE Applied Leading Indicators (ALI) for the remainder of this paper.



Government/Industry Partnership Exploring SE Leading Indicator Concepts and Application
(Rhodes et al., 2009)

The authors set out attempting to focus on why programs fail to meet user expectations at delivery. Our goals were to determine what engineering metrics could be defined and analyzed to provide such insight where programs are apparently not getting such insight today (based upon failure rates of system qualification testing results). This goal lead us to intersect ongoing efforts related to SE ALIs that we determined would provide an understanding of closely related metrics and processes that we would underpin our investigation. The authors have been supporting and co-researching with Naval Air Systems Command (NAVAIR) in Patuxent River, MD, to examine the identification, relevance, and application of SE ALIs. NAVAIR has been examining the ALI concept through engagement with acquisition offices, data gathering and analysis, formulation of predictor algorithms, and prototype ALI tool development. The Systems Engineering Development and Implementation Center (SEDIC) is conducting this NAVAIR effort in collaboration with working groups depicted in Figure 1.

Problem Definition

Program managers apply well-proven and refined program metrics and control mechanisms largely based upon Earned Value Methods (EVM). The EVM fulcrum metrics are cost and schedule that generate analysis outputs depicting variances from plans and estimates. From EVM analysis, program cost and schedule status can be assessed and projection of those parameters can be inferred. Program managers, however, are not provided abundant metrics that can provide insights into the technical health of a development effort and indications of the trajectory of program health, good or bad. Risk metrics and processes provide some indications of technical health but are often qualitative and provide little algorithmic opportunities for prognostics. In general, program managers are faced with the development of complex systems, use EVM and risk management effectively; however, programs are failing to fully control costs and can routinely exceed cost estimates by 25% or more (see Figure 2).

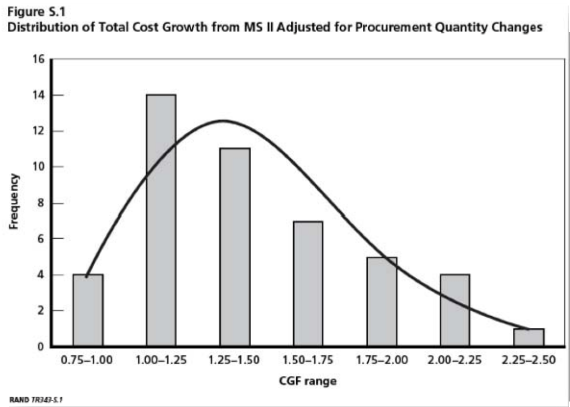


Figure 1. Control of Cost Growth of Programs Remains a Challenge
(Arena, Robert, Murray & Younossi, 2006)

In addition to the quantity of programs that exceed cost estimates, it appears that acquisition cost growth can be attributed to causes centered upon control of technical baselines (see Figure 3). The development of ALIs is intended to gain much more granular insight into the development of the technical baselines as soon as possible to allow for both assessment and predicted program performance so mitigation can be applied. In summary, the specific problem and research response follows:

Problem—Program managers do not have access to adequate technical metrics in order to provide high fidelity assessment of technical health of a complex system development program and quantitative prediction of technical performance.

Research Question—Can SE technical metrics be identified, quantified, and methodically applied to complex system developments to provide technical assessment and leading indications of technical program performance and ultimate success?

Research Objectives:

- Identify relevant data supporting the development of ALIs,
- Identify leading indicators tailored to systems engineering effectiveness,
- Prototype ALI user tools to measure relevance, acceptance, and obtain feedback, and
- Identify new, revised, or derived metrics to support refined ALI methods.

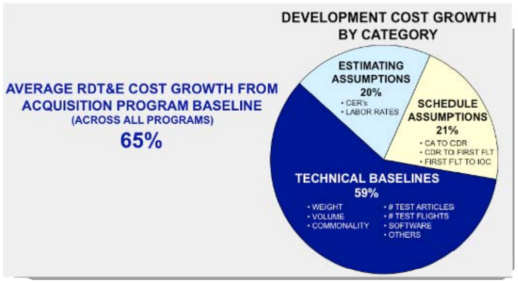


Figure 2. Cost Growth Largely Impacted by Control of Key Attributes of Technical Baselines (NAVAIR 4.2 Division Analysis)

Advance Leading Indicator Concepts

Technical Measurements

SE processes provide metrics, measurements, and analysis activities throughout systems development. These technical measurement activities provide lead system engineers and project managers insight into project technical performance and associated risks. These metrics are most often associated with Measures of Effectiveness (MOEs), Measures of Performance (MOPs), and Technical Performance Measures (TPMs) with associated Key Performance Parameters (KPPs) and Key System Attributes (KSAs). These associations and metrics are qualified through continual testing and often manifest themselves graphically using control chart methods (see Figure 4).

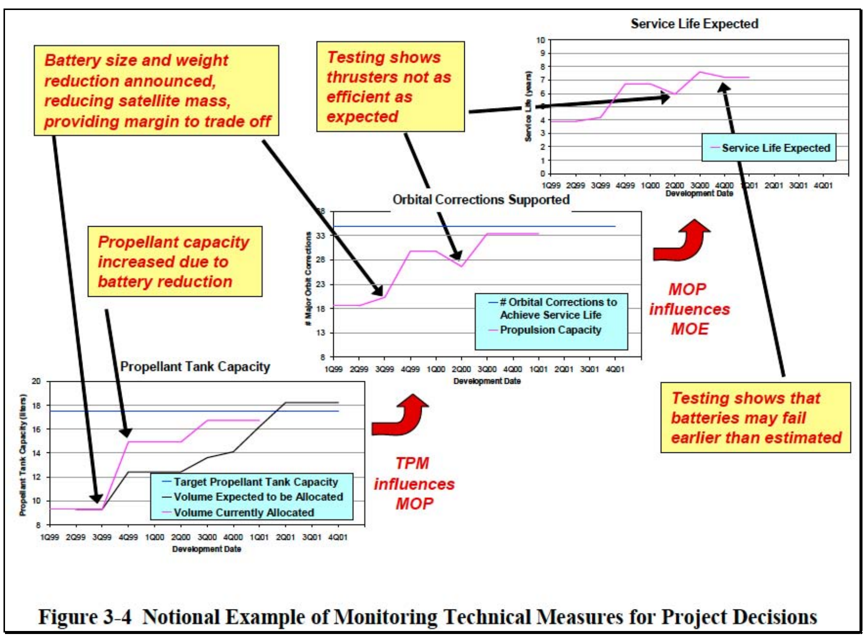


Figure 3. Technical Measures Associated with MOEs, MOPs, and TPMs Guide Testing and Achieving Specifications
(Roedler, 2005)

The above technical measurement processes are often focused on assessing the progress of the system in meeting specification as development unfolds. Although the development of ALIs seems similar to these practices, the intent of ALIs is provide a more holistic and prognostic assessment of the technical aspects of the project by integrating both system technical metrics as well as systems engineering-derived process metrics. ALIs, although substantiated in historical performance of similar projects, are highly forward-looking and technical-rich in fidelity. They are intended to inform the project technical approach and be fully integrated with the program management approach (see Figure 5).

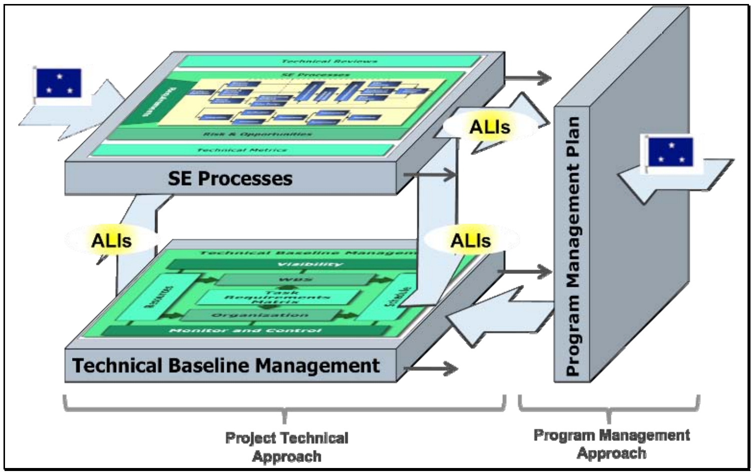


Figure 4. ALIs Provide Metrics Rooted in SE Technical Approach and Supports Program Management Approach

The development and use of ALIs are intended to augment existing program/project management methods, not replace them. Although influenced by many similar metrics (e.g., cost, schedule, etc.), ALIs are derived from system attribute and system engineering metrics to produce technical health and prognostics that enhance the program manager's overall assessment and direction of the project (see Figure 6). They enrich the existing EVM-derived assessment to provide project leadership higher fidelity project technical status and direction that enables greater decision analysis completeness.

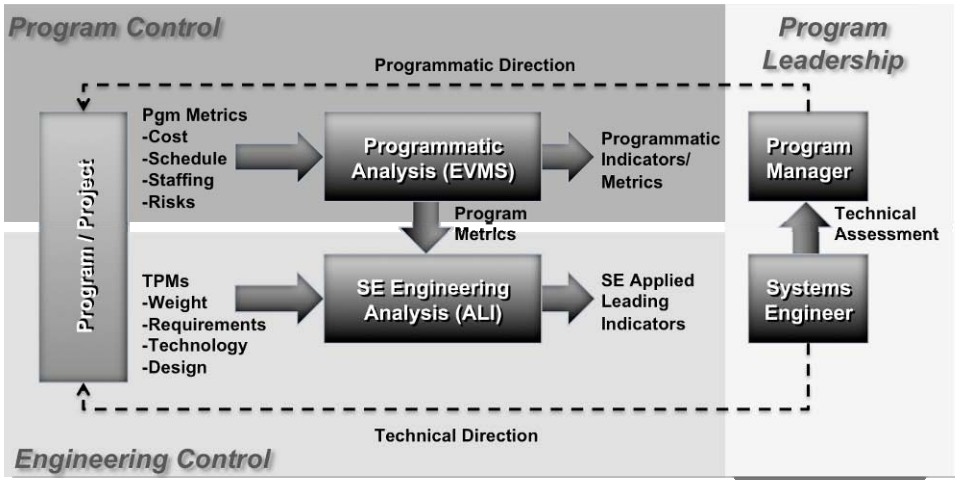


Figure 5. SE Applied Leading Indicators (ALI) Augment Program Management

ALI Approach

Data Selection and Collection

The development of ALIs has progressed through multiple phases. The initial phases identified metrics that were not being integrated into technical assessment that could be derived from engineering activities. The ALI effort is careful to augment program management evaluation methods, not duplicate them. The identification of metrics led to the following list of relevant technical metrics that were considered readily available in program data repositories:

- Aircraft empty weight,
- Software metrics,
- Architecture metrics,
- Requirements metrics,
- Technical review closure burn down rates,
- Reliability, Availability, and Maintainability (RAM) metrics,
- Technical risk metrics,
- Engineering staffing metrics,
- System complexity, and
- Technology maturity.

The data above is collected to form a historical baseline of program performance of similar or related programs (later ALI phases would incorporate current program data to predict future performance). The focus of early research has been associated with the technical metric of *aircraft weight* and subsequent modeling impacts of aircraft weight-growth to program cost-growth throughout development. This data was collected from historical records from the program division records. The data was also "affinitized" or

grouped in like-program categories to maintain relevance of analysis results. Examples of these groupings included aircraft development with similar plan forms (e.g., rotary, fixed wing, remotely piloted, etc.), size of program (ACAT I, II, etc.), and mission (fighter, transports, etc.). In all, approximately 11 programs form the foundation for further data analysis.

ALI Data Analysis

Armed with a single dimension of ALI applicability (weight-growth versus cost-growth), analysis has been conducted to assess what statistical methods can be applied to this data with confidence and with assurance that the methods are representative, relevant, and extensible to provide useful data to program managers. The steps for the early "single-factor" ALI analysis is depicted in Figure 7 and is summarized below.

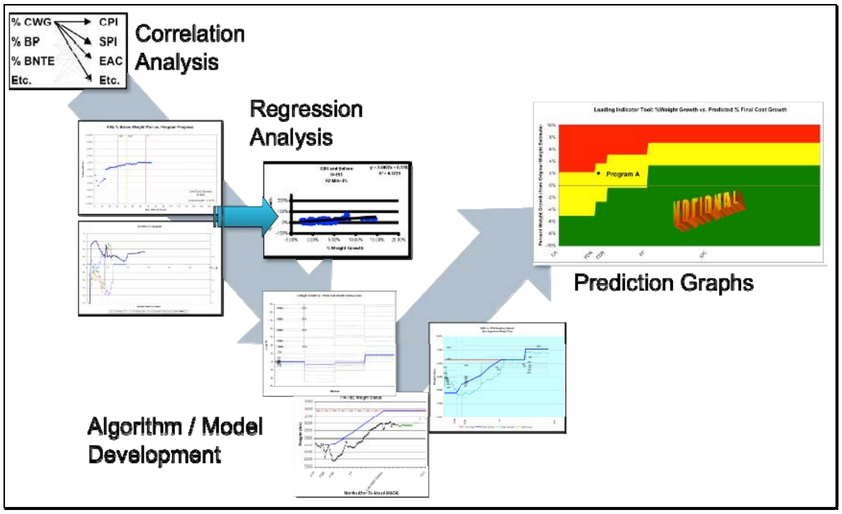


Figure 6. ALI Data Analysis Transforms SE Historical Metrics to Algorithmic, Leading Assessment of Technical Performance and Prototype ALI Tool Development

- **Test for impact (correlation)—**Of several program performance impacts related to aircraft weight throughout development, cost growth proved to be highly correlated and validated and formed the basis for continued analysis.
- **Test for meaningful relationships (regression)—**The ability of weight growth to predict cost growth was examined through several regression methods. The results showed significant statistical strength of using weight-growth as a cost-growth predictor; however, the data must be segmented into major epochs of program development to maximize this predictive strength. The epochs were separated by major design reviews (e.g., PDR, CDR, First Fight, etc.) to ensure predictive usefulness.
- **Derive algorithms to develop prognostics—**The segmented data produced regression formulations with confidence and fit parameters for each epoch and program types. These formulations established historical performance baselines.
- **Validate models against all programs—**The data was validated against the affinitized groupings to ensure that the regression models derived above

provided an accurate model of historical performance of the programs they modeled.

- **Develop "tripwire" boundaries prediction zones—**Although a prediction algorithm was considered useful, it was considered most valuable if cost-growth boundaries could be added to the prediction. These boundaries could be adjusted based upon the interest of the program manager, but as a minimum, would be set at cost-growth conditions that would alert the program manager and leadership of severe program trouble (e.g., 10 USC 2433 (Nunn-McCurdy) limits). These limits were segmented into classic color zones (or "tripwires") of assessment (e.g., red, yellow, and green).
- **Build tool for user validation—**The predictive regression-based formulation was combined with the tripwire assessments/graphics to prototype a user tool for inputting and assessing their program based upon current weight estimates and comparing their current weight estimate (at a particular time of the development) and comparing to historical performance of similar programs to provide a predictor of program cost-growth performan

Early Single-factor ALI Feedback

The user community (program mangers of NAVAIR acquisitions) were presented the output of the tool is depicted in **Error! Reference source not found.** to obtain feedback related to ALI concept and utility. The graphic is described in the following paragraph.

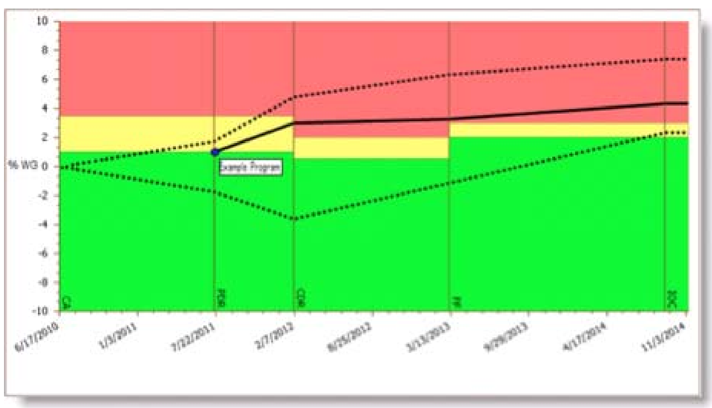


Figure 7. ALI Prototype Tool Provides Cost-growth Prediction Based Upon Similar Program Histories as well as Status of Subject Program
(Denq, Hein & Gilliard, 2009)

The starting "dot" in the yellow zone is the current assessment of an example program. The solid black line is the predicted cost growth of the program based upon where the current program is in comparison to historical performance of similar programs. The dotted lines are confidence bounds of the prediction. This graph, once again, is the depiction of the impact of a single ALI (weight growth) on program cost growth. Early program manager and lead engineer feedback revealed that this graph, although informative to a degree, generates more questions than it answers. Some examples include:

- If single-factor ALI analysis predicts cost growth, what other factors may also impact cost growth?

- What are the impact comparisons among single ALIs?
- Do other ALIs “mutual couple” to cause cost growth?
- What do I (PM/SE) do about it?
- How much is my program like historical programs?
- How can I input my own predictive performance judgment into the algorithm?

Moving to Multi-factor ALIs

The most generalized feedback from program managers and systems engineers to the early single-factor ALI concept is that it needs (1) to consider more ALIs, (2) incorporate their interactions, and (3) algorithmically combine their influences into an integrated ALI metric for the program. Similar to EVM integration of cost, schedule, and achievements (milestone completion) into a few key metrics, ALI needs to work toward that goal. The process for moving to an integrated ALI output is shown in Figure 9.

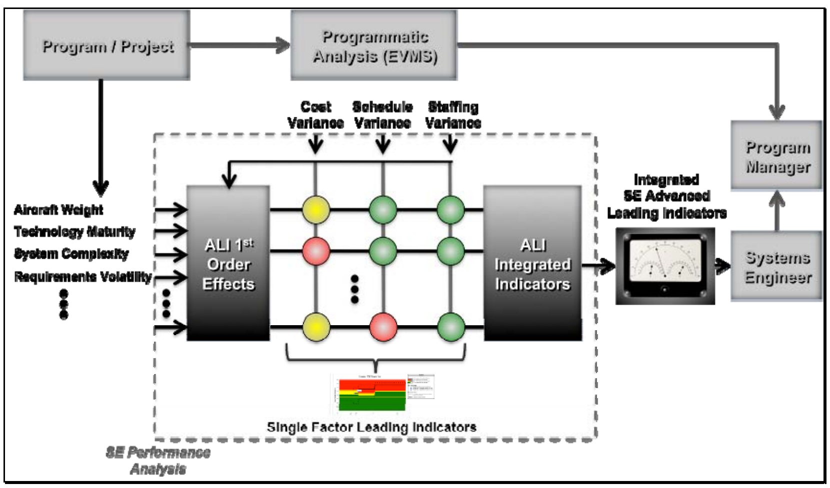


Figure 8. Single-factor ALI Analyses Are First Steps to an Integrated ALI Output

The single-factor ALI analysis and formulations are shown in the center of the diagram. They are analyzed individually and then, after model validation, are integrated to provide a more “global” ALI metric. The repeated analysis steps are depicted in Figure 10. This process has led to an attempt at an integrated, multi-factor ALI approach that is currently being explored.

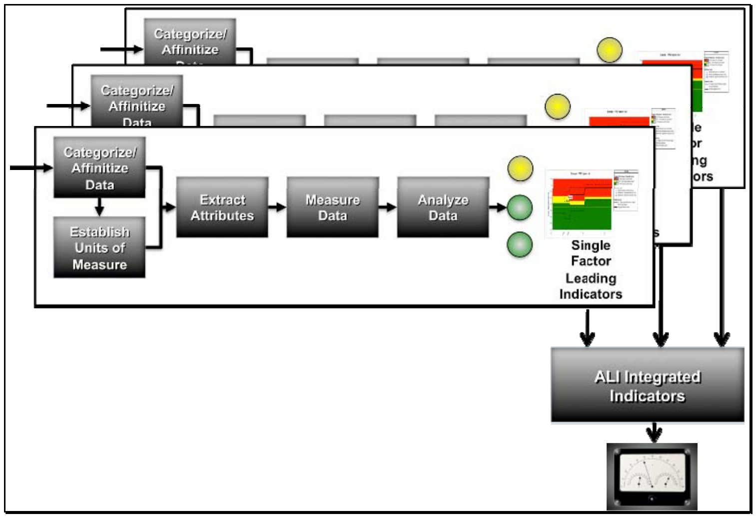


Figure 9. Parallel and Independent Single-factor ALIs Lead to an Integrated ALI for the Program

Multi-factor ALI Development

As discussed above, single-factor ALI development and research has led to the current research into multi-factor ALIs. The underlying assumption is that if a single-factor ALI concept was validated historically, proved some utility in prediction program performance, and had statistical saliencies that could be exploited in a tool, then we may be able to ingest multiple ALI metrics simultaneously and provide meaningful analysis using related statistical methods suited for multi-factor analysis. Ongoing multi-factor ALI investigation (see Figure 11):

- Retains historical data analysis of key program ALI metrics (this maintains a credible baseline of program performance upon which to compare programs).
- Applies multiple regression methods.
- Integrates user assessment of both current conditions and their predictions of individual ALI future performance (e.g., if your program is currently 5% over weight, what is your prediction of how this metric will change in the future?).
- Applies program end-state simulations based upon historical formulation and user estimates. After establishing both historical baseline and associated multiple regression algorithmic models, user predictions are integrated into the models via simulations to predict program performance, fit, and confidence limits.
- Provides integrated multi-factor ALI graphical output to the program leadership.

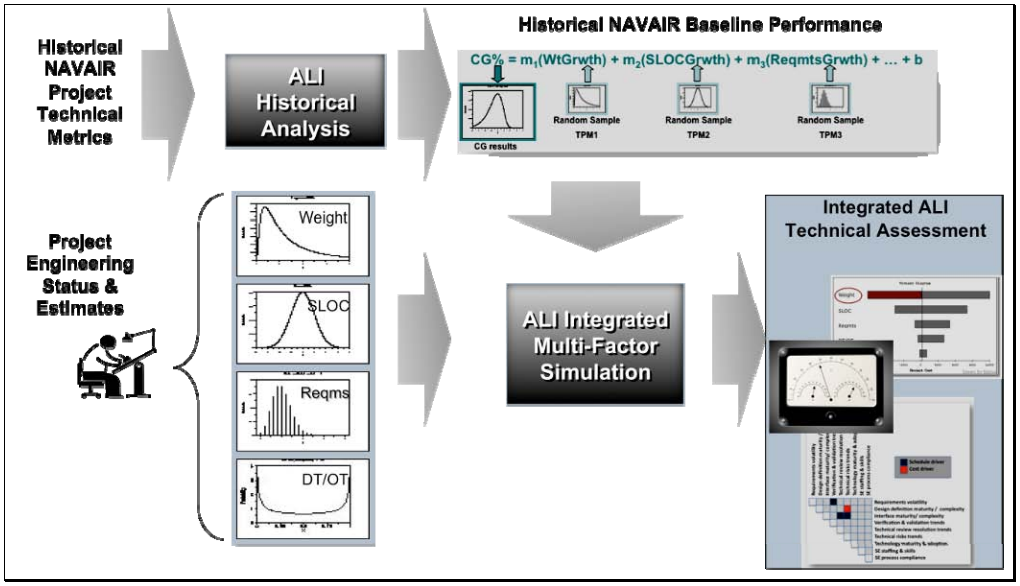


Figure 10. Multi-factor ALI Development/Research Approach

Early graphical concepts are intended to give insights into the “mutual coupling” among the ALIs and their impact on the program. Some concepts include an “interaction matrix” approach (Figure 12, left) showing, for example, which multiple ALIs drive program cost and schedule (indicated by colors) and provide insight into their possible interactions (inferred by their relationships vertically and horizontally). Additionally, from multi-factor ALI analysis, it may be possible to depict which factors are most influential on program performance

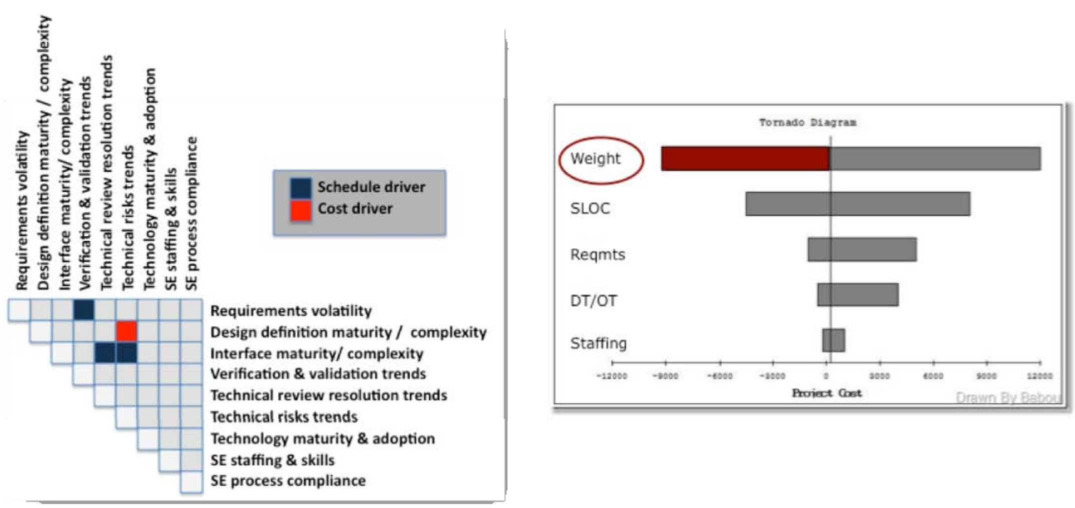


Figure 11. Example of Multiple Alis Influencing Program (Left) Cost and Schedule (Color) and Inferring Their Possible Interactions (Vertical/Horizontal Association) and (Right) Key ALI Influencers

ALI Insight into System Qualification Testing Success

Consistent with the authors' original goals, an NPS capstone project thesis investigated using the available ALI analysis data to gain insight into how programs were succeeding in their qualification testing (Buchanan & Jungbluth, 2010). Their research indicates some promising, although weak, statistical inferences about the data and successful testing outcomes. Their work sets foundations for further research discussed below.

Results and Conclusions

Although this ALI research is in the early stages, the ALI strategy, methods, and results discussed in this paper show promise for providing program manager and lead system engineer insight into the current and predicted technical success of their programs. This has been demonstrated through ALI data analyses, ALI user tool prototypes, and user acceptance testing.

This research began with a focus on why programs fail to meet user expectations at delivery. The goal is to determine what engineering metrics can be defined and analyzed to provide insight into success of qualification testing (e.g., operational test and evaluation, validation, etc.). This goal lead us to intersect ongoing efforts related to SE ALIs that we determined would provide an understanding of closely related metrics and processes that would underpin our investigation. The ALI research is still formative and evolving and the following conclusions are mostly qualitative (non parametric) but help to refine further directions related to ALIs and original research goals.

Data—Although there are rich data repositories available in the case of NAVAIR, the data can be inconsistent and incongruent. This increases difficulty in data analysis and bounding uncertainty in the predictive credibility of the ALI algorithms and tools. Additionally, retention of data from various programs is sometimes incomplete, leading to statistical analysis of sparse data. These problems are not, however, insurmountable and occur regularly in statistical analysis activities. The benefit of the ALI investigation is that recommended ALI metrics will emerge that can be recommended to be inculcated into the acquisitions to enable greater future ALI fidelity, granularity, and reliability.

Single-factor ALI analysis—The weight-growth versus cost-growth ALI analysis revealed that the development method was valid, provided a basis for ALI tool prototyping, and garnered preliminary user acceptance, understanding, suggested improvements, and identified ALI concept shortfalls. The technical basis is strong; however, the most impactful recommendation from users was to demand *multi-factor* ALI methods.

Note: When we tried a "programmatic" metric (staffing-growth versus cost-growth) as a comparison, the statistical predictive strength was not as strong as the technical metric of weight. The resulting conclusion was that there are many external factors (re-baselining, inter-program staff balancing, etc.), which weakened statistical fit. Additionally, although we have some interest in multi-ALI interactions with programmatic metrics, we discontinued the staffing investigation because it proved too parallel with programmatic metrics (i.e., EVM).

Multi-factor analysis—These methods and analyses are in very early stages. Early models and processes are employing data from the same programs, leveraging single-factor analysis lessons learned, expanding to include multivariate statistical methods, and new graphical output techniques. Early indications using simulated modeling data show promise.

The next steps will include actual data, validate multivariate models, and prototype a tool to garner user acceptance.

ALI metric expansion—The only metric that was validated was aircraft weight and its growth throughout the development cycle. More metrics still need to be developed and incorporated into the research.

User acceptance—Users recognize the need for a method based upon technical metrics to provide predictive program performance insight. They do not, however, want ALI to replicate EVM-based metrics and methods. Additionally, they desire ALI methods to incorporate prediction inferences and judgments of the project engineering and management team to influence analytical output. Finally, as stated earlier, user inputs showed a strong need to reveal mutual coupling of the multiple ALI factors, the overall impact to the program, and insights into how to respond, technically.

Areas for Continuing Research

Multi-factor ALIs—As stated above, this analysis is in the early phases and needs to be completed to the point of testing, validation, and user acceptance/feedback. The next steps are to include ingesting actual data, validating multivariate models, and prototyping a tool/user interface to gain insight into user acceptance

Total-ownership-cost control—During the conduct of this research, there is a “sea change” underway toward Total Ownership Cost (TOC) control at NAVAIR. This potentially shifts the types of ALI metrics but the fundamental single and multi-factor analysis will, most likely, remain viable. The nature of a TOC data gathering, algorithm development, and tool may have to be reengineered to ensure customer acceptance and TOC problem relevance. Specifically, the following areas will need addressing:

- What are the salient TOC assessment goals and objectives?
- What are the ALI metrics most relevant to TOC assessment?
- What TOC ALI human interaction interfaces would be most useful to users?

Qualification and acceptance metrics—We will continue to investigate how ALI metrics (or derivatives) might be viable for also monitoring, controlling, predicting, and maximizing success of system qualification testing. Expanding and defining metrics and methods relative to predicting and analyzing program qualification and acceptance test success remains a goal.

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- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-tem Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness
- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)

- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
- Strategic Sourcing

Program Management

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
- Managing the Service Supply Chain
- Measuring Uncertainty in Earned Value
- Organizational Modeling and Simulation
- Public-Private Partnership
- Terminating Your Own Program
- Utilizing Collaborative and Three-dimensional Imaging Technology

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Systems Engineering Applied Leading Indicators

Enabling Assessment of Acquisition Technical Performance

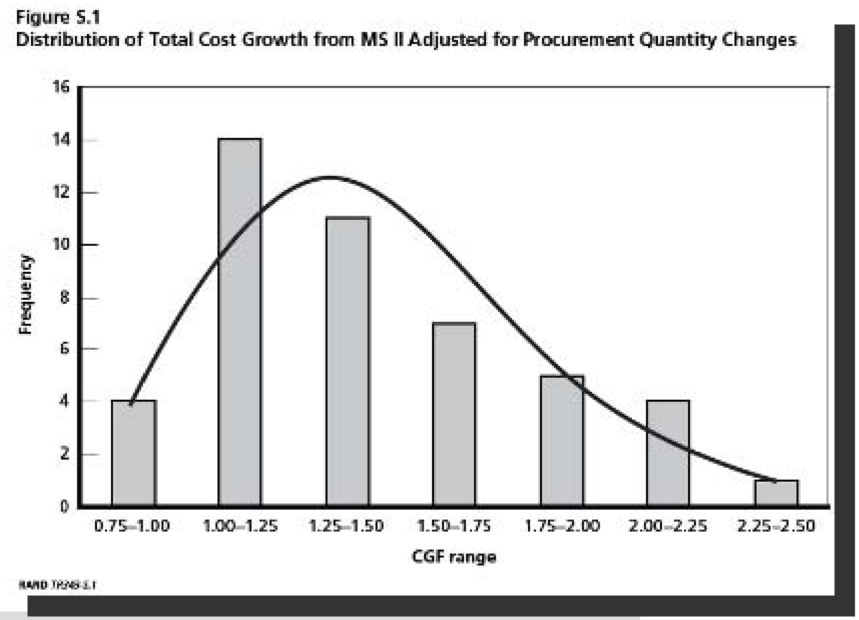
Dr. Paul Montgomery (Assoc Prof of SE)
Ron Carlson (Prof of Practice of SE)
Naval Postgraduate School

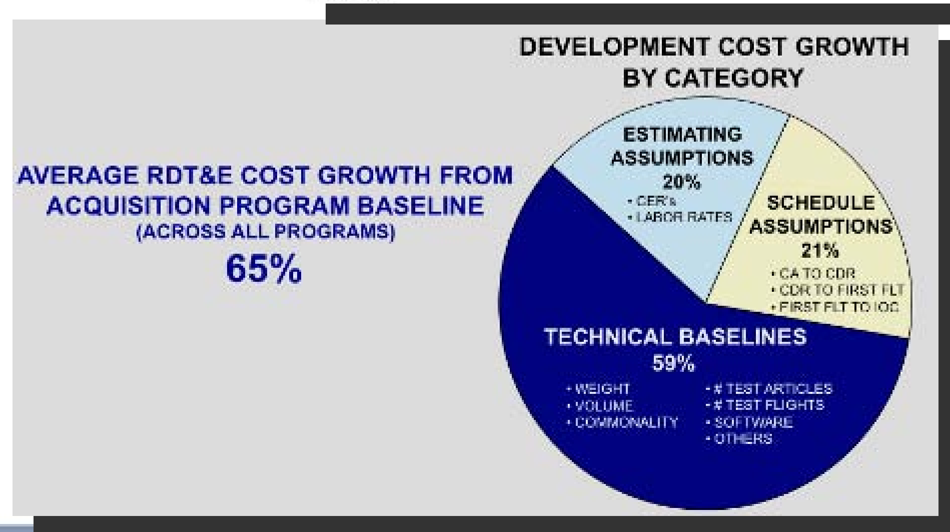
ALI - Applied Leading Indicators (Part 1 of 2)

- What problem are we trying to solve?
- How do ALIs integrate into current management practices?
- How can ALIs benefit programs?

What is the Problem?

- Cost
- Complexity
- Risk Control
- Integration
- Predictability
- Acceptability





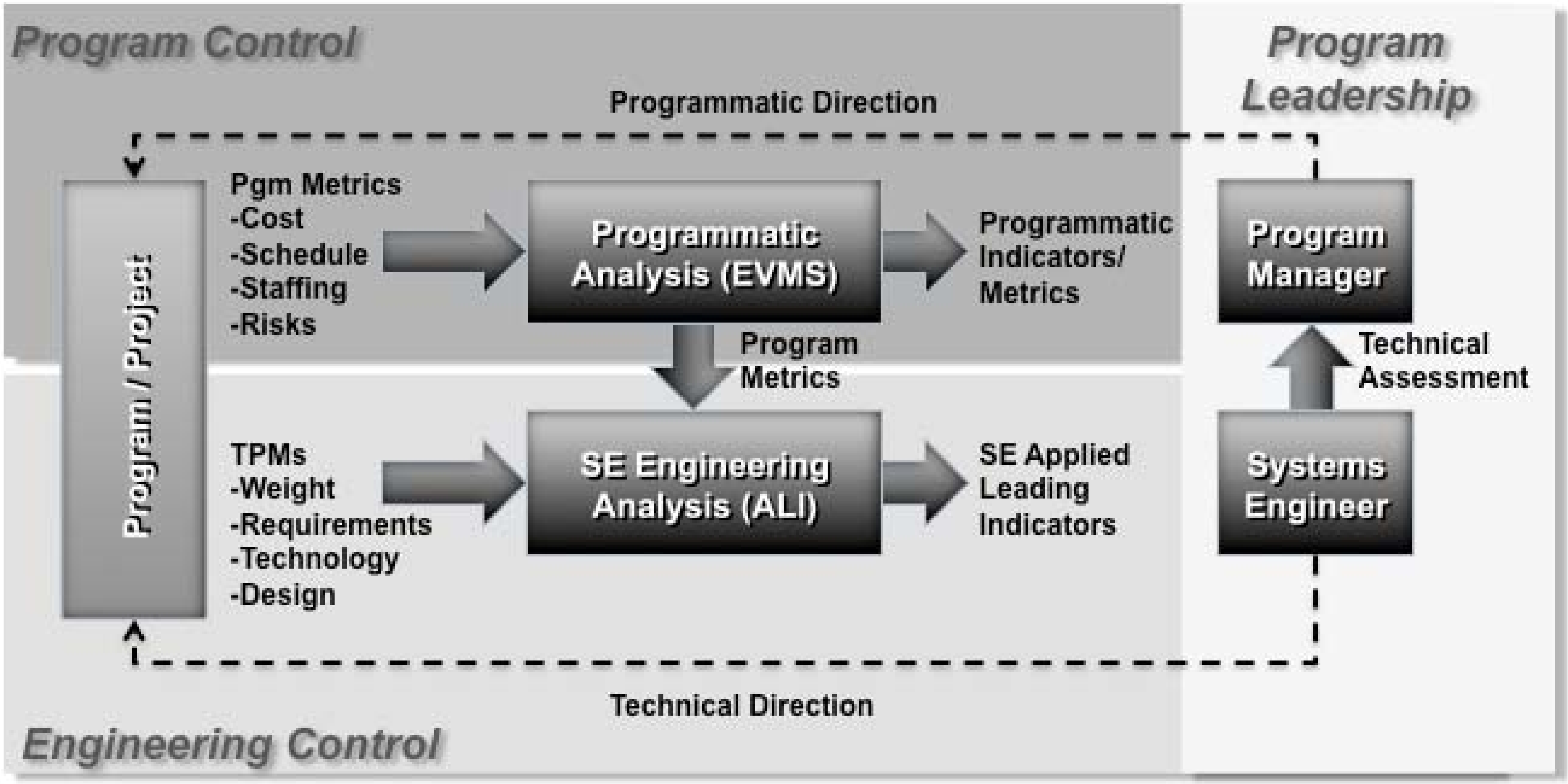
The SE – ALI Challenge

- Can we provide a **quantitative projection** of how varied and interrelated technical factors are impacting overall program performance?
- Can we provide **current and projected** program performance?
- Can we **fill a gap** that currently exists between technical measures and overall program performance measures?
- Can we **augment** current program health and status methods and tools with supporting and parallel technical methods?

ALI – Augments Program Management Processes

- **Program Metrics**
  - **Cost & Schedule** – based (EVM)
  - Focused upon actuals vs. planned data
  - Largely measures **now vs. past**
  - Projecting $/time-to-complete based upon current trajectories
- **Risk Management**
  - Cost, schedule, and performance
  - Assessments heavily based on history, experience, and judgment
  - **Risk/issue** updates are based on **now**
  - Root cause analysis based on past performance and helps suggest course changes
- **SE Advanced Leading Indicators**
  - Collaborative with Program and Risk metrics
  - **Future-**focused (prognostic)
  - **Performance/technical**-focused (vice cost/schedule)
  - Provides needed SE insight of **technical interactions and dependencies** not readily apparent through other metrics

ALI Augments Program Management



SE Leading Indicators Examples

- Requirements volatility
- Design definition maturity / complexity
- Interface maturity/ complexity
- Verification & validation trends
- Technical review resolution trends
- Technical risks trends
- Technology maturity & adoption
- SE staffing & skills
- SE process compliance
- NAVAIR-unique
  - Aircraft weight trends
  - …(TBD)

Note: *Some of these are currently measured as program TPMs but not used to develop prognostic technical indicators*

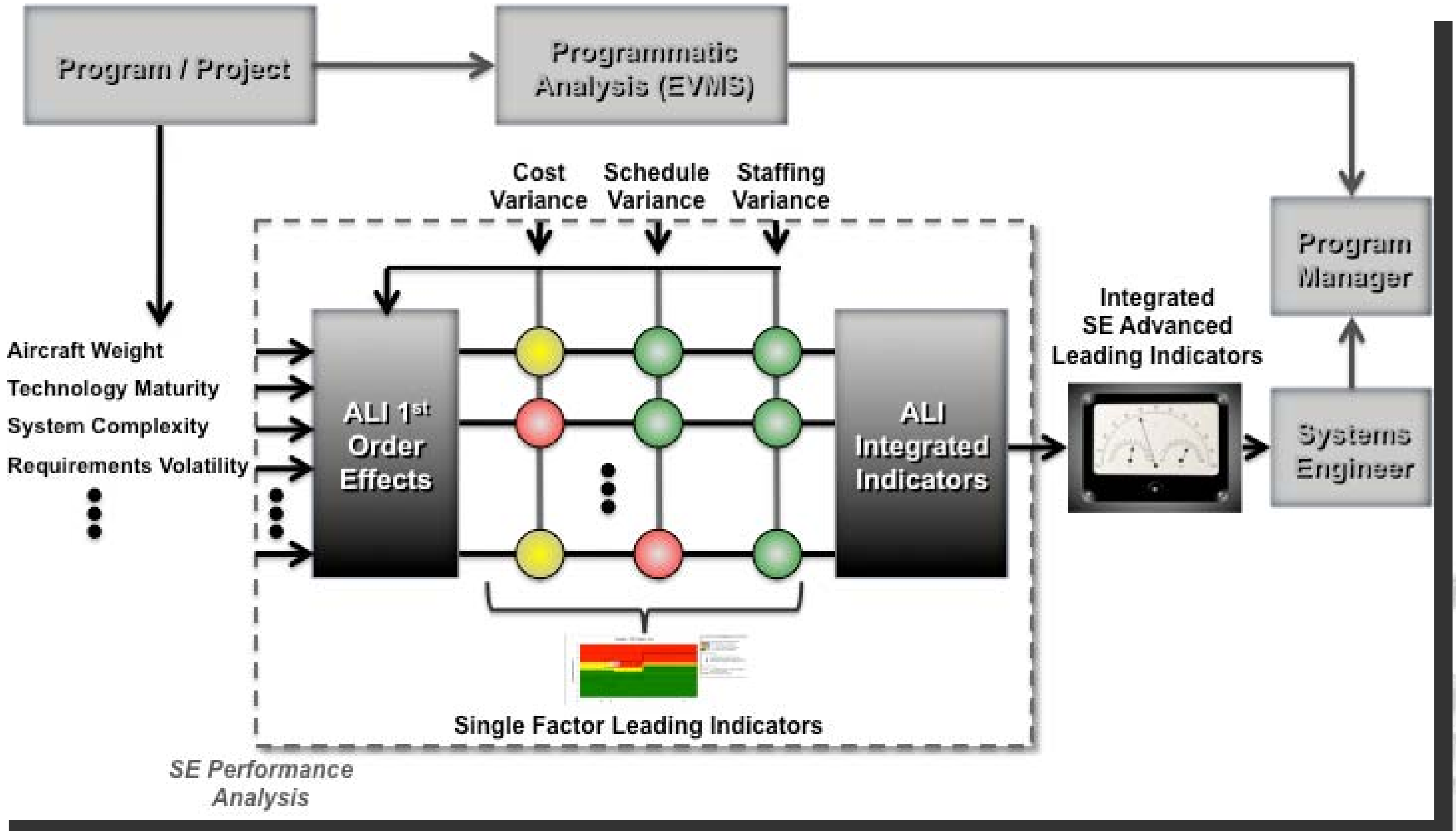
ALI - Possible Value-Added Examples

- **EVM validation**
  - Your program looks good from cost, schedule, and milestone achievement. How does your program *technical* health compare to those who have gone before you with similar EVM assessments?
- **Integrated technical assessment**
  - You have recently re-baselined. How do the *complexity* of your design and recent *requirements volatility* impact your probability of meeting program and performance objectives?
- **Risk amplification**
  - Root cause analysis suggest several course corrections for your technical approach. What SE leading indicators help select a path?

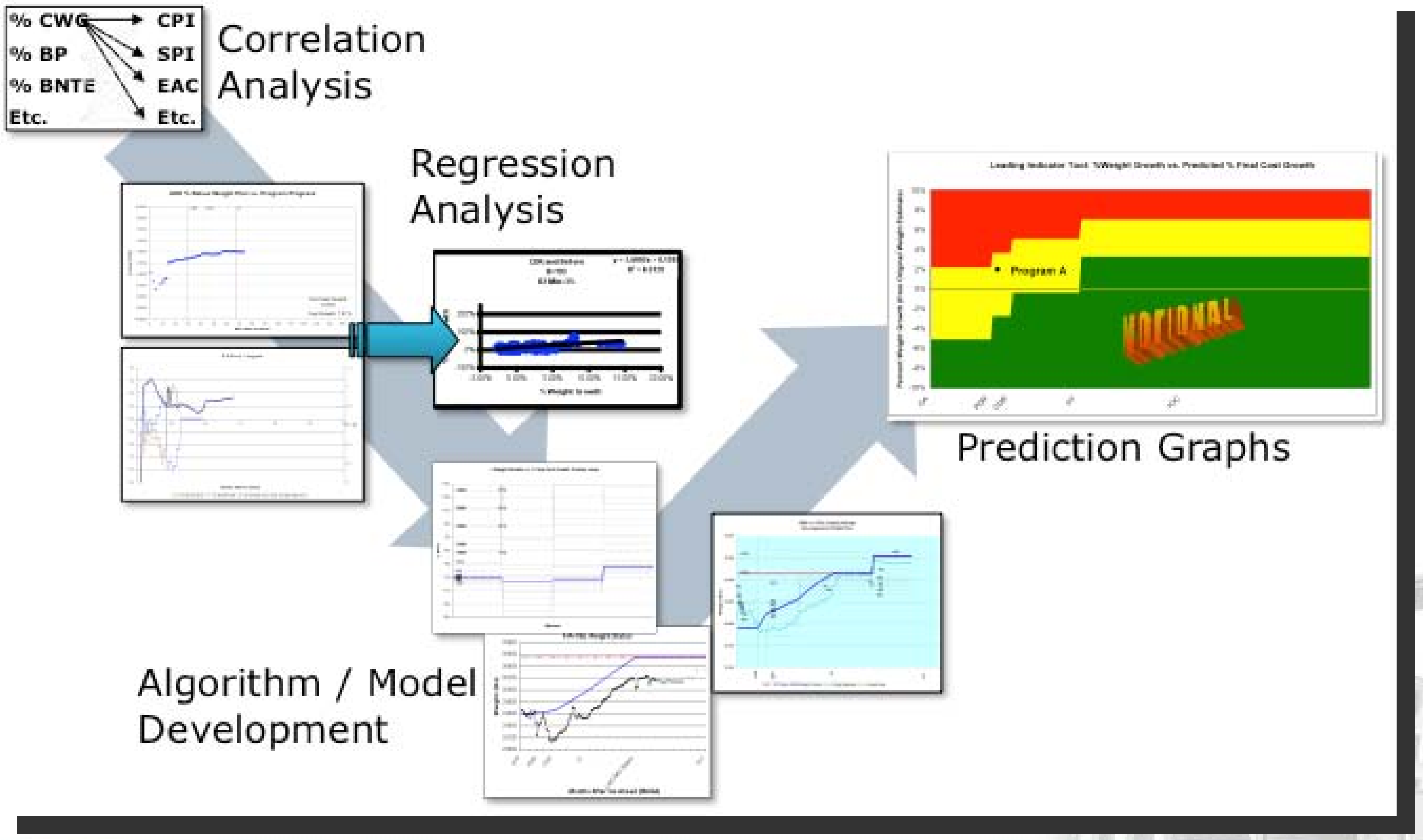
ALI - Applied Leading Indicators (Part 2 of 2)

- How are we building ALIs?
- What have we learned?
- Where do we go from here?

SE ALI Process Summary

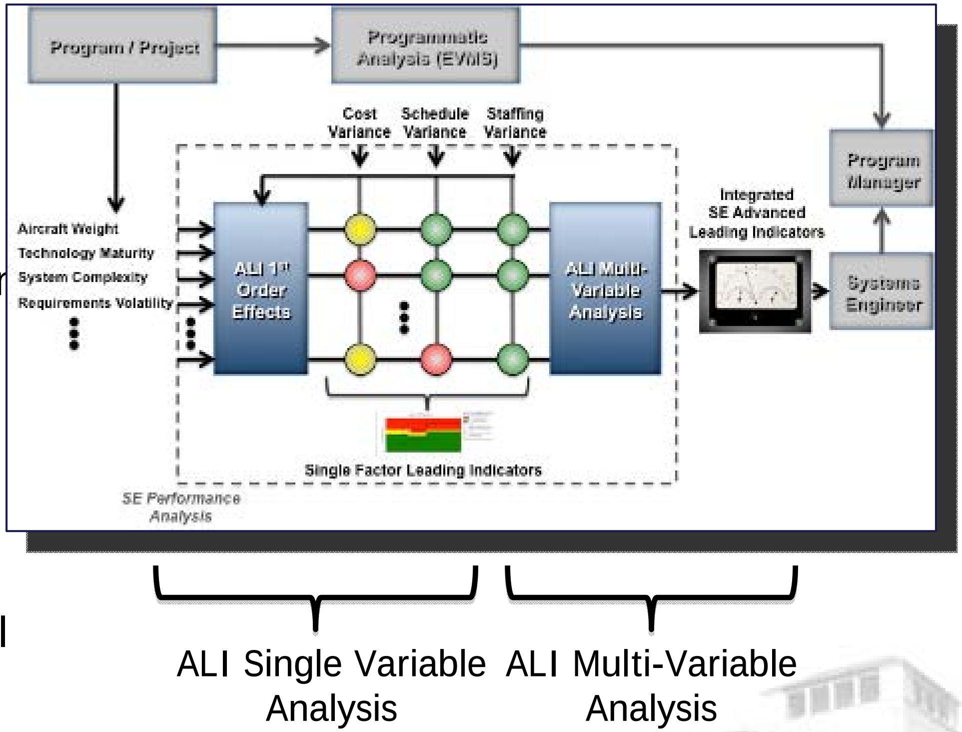


ALI Analysis Method

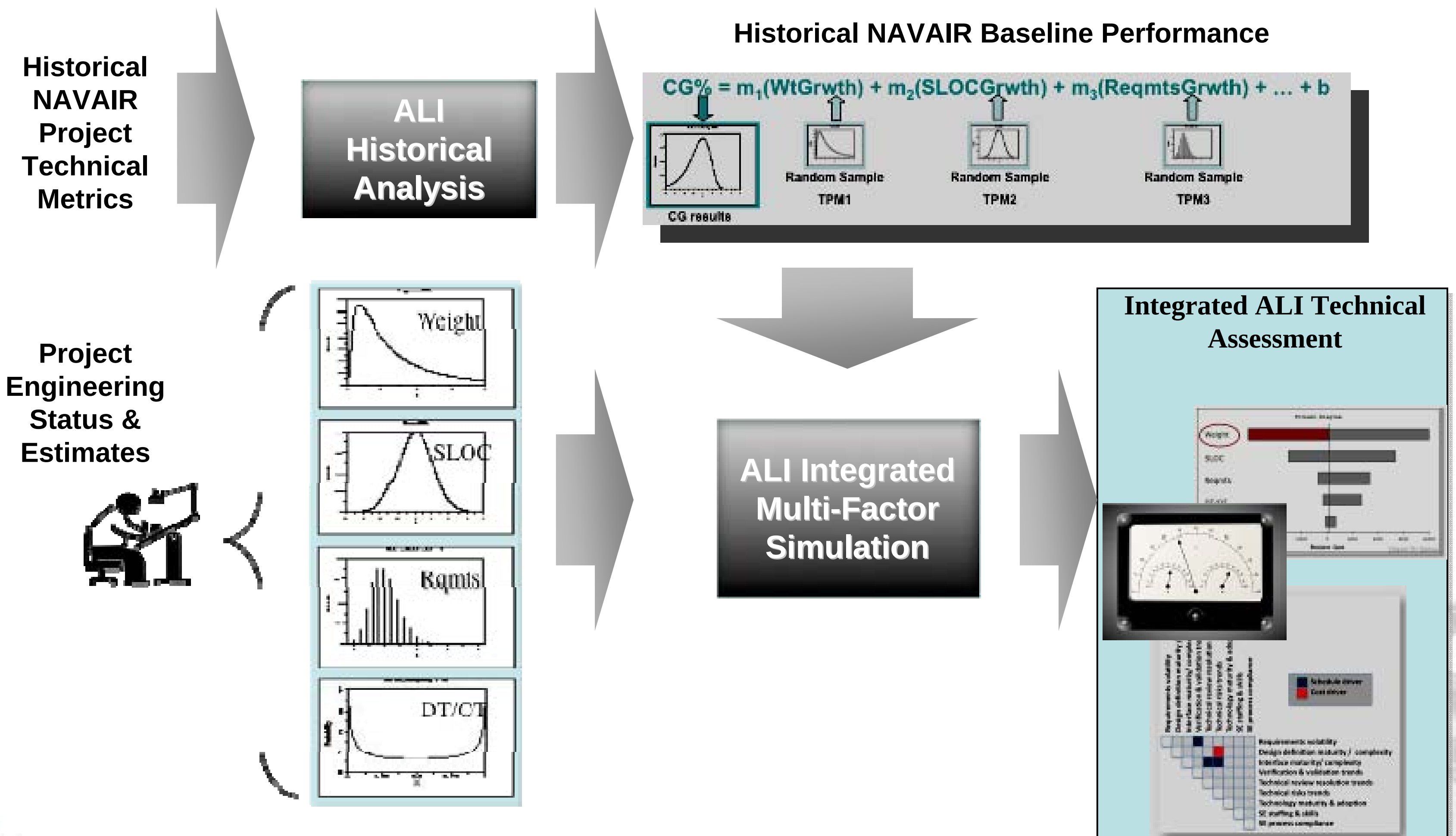


The SE-ALI Challenge (Progressing from Single to Multiple Variable Analysis)

- **Program performance**
  - Can we provide current and projected program performance using SE-based metrics? *(ALI single factor process– to date)*
- **Explaining inter-relationships**
  - Can we provide a quantitative projection of how varied and interrelated technical factors are impacting overall program performance? *(emerging Multi-Variable process)*
- **Enhance current metrics**
  - Can we fill gaps that currently exist between technical measures and overall program performance measures?
- **Supporting current methods**
  - Can we augment current program health and status methods and tools with supporting and parallel technical methods?



Multi-Factor Technical Approach



Conclusions & Lessons-Learned: Data

- Data can be inconsistent and incongruent.
- Retention of data from various programs is sometimes incomplete leading to statistical analysis of sparse data.
- ALI metrics will emerge that can be recommended to be inculcated into the acquisitions to enable greater future ALI fidelity, granularity, and reliability.

Conclusions & Lessons-Learned: Single Factor ALI

- Single factor ALI analysis
  - Development method was valid
  - Provided a basis for ALI tool prototyping
  - Obtained preliminary user acceptance, understanding, suggested improvements
  - Identified ALI concept shortfalls.
  - Users demand multi-factor ALI methods

Conclusions & Lessons-Learned: Multi-Factor Analysis

- In very early stages.
- Leveraging single-factor analysis lessons-learned
- Applying multivariate statistical methods
- New GUI concepts
- Next steps will expand to other ALI factors, include actual data, validate multivariate models, and prototype a tool to obtain user acceptance feedback

Conclusions & Lessons-Learned: User Acceptance

- Users recognize the need for ALIs
- The do not, however, want ALI to replicate EVM-based metrics and methods.
- They desire ALI methods to incorporate prediction inferences and judgments of the project engineering and management team to influence analytical output
- ALIs need to reveal mutual coupling of the multiple ALI factors, the overall impact to the program, and insights into how to respond, technically.

Next Steps

- Multi-factor ALIs
- “Sea change” underway toward Total Ownership Cost (TOC) control at NAVAIR.
  - What are the salient TOC assessment goals and objectives?
  - What are the ALI metrics most relevant to TOC assessment?
  - What TOC ALI human interaction interfaces would be most useful to users?